AD-A125 557 DIGITAL SYSTEMS TECHNICAL ANALYSIS(U) ARINC RESEARCH CORP ANNAPOLIS MD L H HOGLE ET AL. OCT 82 1469-01-1-2804 DOT/FAA/CT-82/129 DTFA03-81-C-0079 1/1

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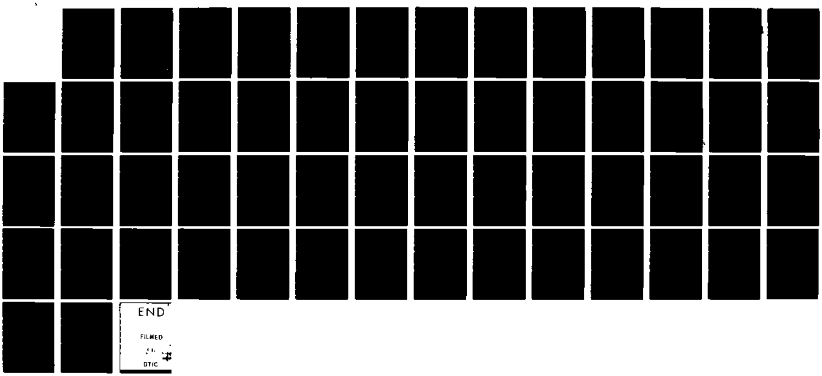

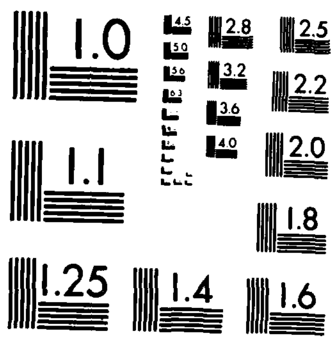

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Digital Systems Technical Analysis

AD A125527

L.H. Hogle
P.D. Blythe

October 1982

Final Report

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US Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-82/129		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code / 8. Performing Organization Report No.
DIGITAL SYSTEMS TECHNICAL ANALYSIS	5. Report Date: October 1982
	6. Performing Organization Code:
7. Author(s): L. H. Hogle and P. D. Blythe	8. Performing Organization Report No.: 1469-01-1-2804
9. Performing Organization Name and Address: ARINC Research Corporation, 2551 Riva Road, Annapolis, Maryland 21401	10. Work Unit No. (TRAIS):
	11. Contract or Grant No.: DTFA03-81-C-00079
12. Sponsoring Agency Name and Address: Department of Transportation, Federal Aviation Administration Technical Center, Altantic City Airport, New Jersey 08405	13. Type of Report and Period Covered: Final Report
	14. Sponsoring Agency Code: ACT-340

15. Supplementary Notes

16. Abstract

This study analyzed currently available data specifically related to the reliability of digital avionics systems. It examined the relationships between reliability and airworthiness standards, maintenance programs, integrity, and safety.

The data presented support the contention that digital systems are capable of performing more reliably than comparable analog systems. Concerns are expressed, however, relative to such considerations as fault propagation, software configuration control, and electrical static discharge.

The study concludes with the suggestion that a standardized reliability data base that included reference to cause of failure could be useful in directing attention to means of improving unit reliability.

17. Key Words	18. Distribution Statement
Digital Avionics Reliability Data Base	This document is available to the U.S public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	55	

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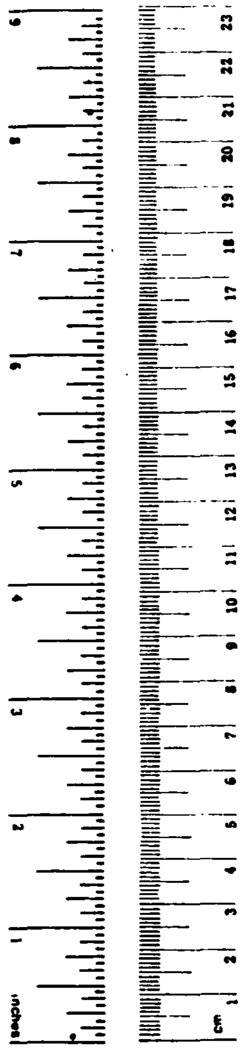
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

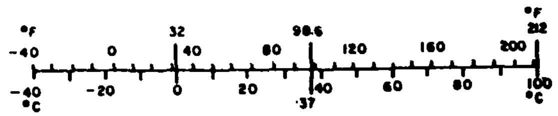
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENT

This study was performed for the Federal Aviation Administration Technical Center, Atlantic City Airport, New Jersey. The Contracting Officer's Technical Representative for the Technical Center was Mr. Joseph J. Traybar, Flight Safety Research Branch (ACT-340). He was assisted by Mr. Donald Eldredge (ACT-340).

The data presented in this report were obtained through the cooperation of numerous corporations. We gratefully acknowledge the contributions of the following:

- American Airlines
- Avionics Maintenance Conference
- Bendix Corporation
- Delta Air Lines
- Douglas Aircraft Company
- Eastern Air Lines
- Hamilton Standard
- Lockheed-California Company
- Northwest Orient
- Piedmont Airlines
- Rockwell/Collins
- Sperry Flight Systems
- Trans World Airlines
- United Airlines

We are also indebted to Mr. G. F. Quinby, aviation consultant to ARINC Research, for his valuable contributions to the preparation of this report.

SUMMARY

This report documents the work performed by ARINC Research under contract to the Federal Aviation Administration Technical Center to perform a technical analysis of digital systems in current-generation aircraft, both commercial and general aviation. The purpose of this study was to assist the FAA in its efforts to assure the operational safety and reliability of future software-based, integrated digital avionics by analyzing currently available data on digital systems.

Reliability data were obtained on both air carrier and general aviation digital systems within the following categories: navigation, communications, flight instruments, flight data, and autopilot and flight controls. The analyses focused on identifying the relationships between performance of digital avionics and the following variables of interest: failure rate, system category, system design, and system application. The relationships of reliability to existing airworthiness standards, maintenance programs, integrity, and safety are also presented.

The data presented indicate that digital systems are capable of performing more reliably than comparable analog systems. The data suggest that a mean time between removal in excess of 2,000 hours is generally achievable through digital design. It is also shown that the number of removals of digital units remains, on the average, twice the number of confirmed failures, as has historically been the case for analog units.

During the data collection process, it was found that there are differences in reliability-reporting formats between airlines and between avionics manufacturers. The variations generate some difficulty in developing a composite representation of the reliability of digital avionics. In addition, although the advent of digital technology has enhanced the functional capabilities of avionics, the user community expressed some concern regarding aspects of the implementation, use, and maintenance of digital systems. These concerns include fault propagation, software configuration control, and electrical static discharge.

Data bases on unit reliability that include information on the cause of failure can serve as indicators of where emphasis should be placed to improve unit design and maintenance procedures.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Traditionally, the criteria for certification of flight control and avionics systems were developed on the premise that the systems were non-integrated and analog. These older systems were single-function, discrete devices that were amenable to relatively simple performance measurement and evaluation tests. With the advent of integrated-circuit digital technology, the Federal Aviation Administration (FAA) was presented with a wide range of complex new safety and certification issues.

The FAA Technical Center is supporting the development of techniques for measuring the acceptability of digital systems. The primary objectives of the Technical Center are to establish research activities and provide information and data bases related to the performance, reliability, verification, validation, criticality assessment, and configuration management methodologies for existing and new digital systems.

Any recommendations concerning acceptance criteria for digital systems must be based on past, present, and projected problems specifically related to digital systems and their integration into the aircraft. The FAA Technical Center tasked ARINC Research Corporation to acquire, define, and analyze data associated with digital system problems. The results of that activity are presented in this report.

1.2 PURPOSE

The purpose of the project was to assist the FAA in its efforts to assure the operational safety and reliability of future software-based, integrated digital avionics by analyzing currently available data on digital systems. Project activities were concentrated on the establishment of a data base of past and current performance and the formulation of recommendations for continual updating with data on new and emerging components and systems.

1.3 SCOPE

The project encompassed acquiring, defining, and analyzing data related to the implementation, use, and maintenance of digital flight control and avionics systems. System implementation considerations included those minimum performance and quality control standards which provide assurance that a system satisfactorily performs its intended functions. System use considerations included the performance and reliability of the system as perceived by pilots, maintenance personnel, purchasing agents, and manufacturers. System maintenance considerations included the techniques used for fault isolation and diagnosis and the practices employed to maintain optimal system performance.

The project efforts were divided generally into five areas:

- Identification of systems of interest (i.e., systems that are currently in production and in service)
- Acquisition of data on system performability (ability to maintain the performance of intended functions)
- Identification of units that are in production but are not currently in use (e.g., B-757 and 767 equipment), and units that are not system-oriented (e.g., low-cost general aviation units)
- Analysis of data
- Recommendation of mechanisms for establishing, maintaining, and updating the data base

1.4 TECHNICAL APPROACH

Three phases of effort were developed for this project.

1. Determine present status of advanced, integrated digital flight control and avionics systems
2. Analyze current system problem areas
3. Reach conclusions concerning methods for evaluating existing and new systems

During Phase 1, an industry search was conducted to identify the present status of digital flight control and avionics systems. The information of interest included the quantities of digital systems currently in use and the function and application of each system. Sources of data included previously performed market surveys, equipment logs of major users, and product marketing information from technical documents and brochures.

The Phase 2 analyses required in-depth interviews with avionics manufacturers, airline operators, and other knowledgeable experts. Detailed data were solicited for the purpose of establishing a base of system performance and reliability data applicable to system implementation, use,

and maintainability. The data obtained were reviewed, collated, and analyzed to identify critical relationships within or between avionics systems that adversely affect operational performance and reliability.

The results of Phases 1 and 2 were used in Phase 3 to develop conclusions about the need to initiate efforts that would support effective implementation, use, and maintenance of digital systems.

1.5 REPORT ORGANIZATION

Chapter One has provided the background, purpose, scope, and technical approach of the study.

Chapter Two presents the categories of digital systems which were addressed in the study and to which the results of the study are most applicable.

Chapter Three provides insight into the reliability of avionics and examines the relationship between reliability and safety.

Chapter Four describes existing practices for reliability reporting and records maintenance.

Chapter Five presents the data collected and describes the methods used to collect and organize the data.

Chapter Six presents analyses of the data.

Chapter Seven is a discussion of issues pertinent to the certification of digital systems.

Chapter Eight presents conclusions.

The Appendix is a glossary of terms.

CHAPTER TWO

DIGITAL SYSTEM CATEGORIES

2.1 CATEGORIES INVESTIGATED

The systems considered pertinent to this study are digital flight control and avionics systems, including navigation and sensor systems. The following list identifies equipments that employ some degree of digital circuitry and were therefore investigated:

- Flight Data Systems
  - Performance data systems
  - Flight data recorders
- Autopilot and Flight Controls
  - Autopilot
  - Flight controls
- Flight Instruments and Navigation Systems
  - Flight instruments
  - Air data computers
  - Compass systems
  - Stall warning
  - VOR/LOC/ILS
  - Marker beacon
  - ADF
  - Weather radar
  - DME
  - ATC transponder
  - Radio altimeter
  - Thrust rating
  - Flight director
  - INS

  - Omega navigation
  - Loran-C navigation
  - VOR/DME area navigation
  - Ground proximity warning
- Communications Systems
  - HF communications
  - VHF communications
- Electronic Engine Controls

A list of digital systems was compiled from the response of industry representatives and from literature searches, including in the list some analog systems for comparison. Data were collected, compiled, and analyzed on each of the systems. The analyses focused on identifying the relationships between unit removal rates and the following variables of interest:

- System Category
- Failure Rate
- Design
  - Analog
  - Digital
- Application

The study revealed that a particular avionics unit can be considered digital by some and analog by others. Each of the following system characteristics was offered as the determining factor in classifying a system as digital:

- Digital data transfer (e.g., modems)
- Digital data processing (e.g., digital DME)
- Microprocessor-based design with user-accessible memory (e.g., flight management systems)

It is difficult to rank these characteristics according to design complexity, since it cannot be assumed that a unit with user-accessible memory is more complex, or even more functionally capable, than a unit without such memory. An obvious distinction between different forms of digital system implementation is the level of dependence on software. Systems that are software-based can be modified with respect to functional capability without accompanying hardware changes. Software changes are generally transparent to the user in the sense that he cannot know that a change has been made unless the change manifests itself in a dramatic way. Subtle changes go largely unnoticed, providing little opportunity to verify system integrity. The introduction of user-accessible memory increases the

potential for diminishing system integrity through memory changes that might introduce difficult-to-detect errors.

For this study, a unit was considered digital if it performed some form of discrete processing, through either LSI or microprocessor implementation, with or without the use of software.

2.2 CATEGORIES OF APPLICATION

The digital systems listed in Section 2.1 were evaluated, in the light of the defined variables of interest, for two separate categories of application: air carrier and general aviation. The air carrier segment of the civil fleet is limited to aircraft operated under Federal Air Regulations (FAR) Part 121* and Part 127.** The remaining aircraft in the civil fleet are considered general aviation, including the air taxi, commuter, and commercial operators regulated by FAR Part 135†. The following sections identify the distinctions between the air carrier and general aviation environments with respect to the application of digital avionics and flight control systems.

2.2.1 Air Carrier System Usage

The U.S. air carrier fleet comprises approximately 2,750 aircraft. The major aircraft represented in the fleet are the B-727, B-737, B-747, DC-9, DC-10, and L-1011. These aircraft are flown, typically, 200 to 250 hours per month, with the time varying as a function of operator and aircraft type. With yearly operating times of 2,400 to 3,000 hours per aircraft, it is important to the carriers to have sufficient reliability in their avionics to minimize the need for frequent maintenance and repair. Avionics with a mean time between failures (MTBF) of 1,000 hours would require repair three times a year. Further, the avionics usually are installed at the time of airframe manufacture and are generally replaced during the useful life of the aircraft. This long period of anticipated maintenance results in an emphasis by air carriers on avionics designs that reduce maintenance costs rather than minimize acquisition cost.

2.2.2 Use of General Aviation Systems

The general aviation fleet has about 210,000 active airplanes, ranging from low-performance, single-engine aircraft to high-performance, multi-engine jets. There is a wide diversity of aircraft missions and pilot proficiencies in the general aviation community. However, general aviation aircraft use the same air traffic control and navigation systems as the air carrier fleet. The avionics in the general aviation aircraft must per-

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*"Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft."

**"Certification and Operations of Scheduled Air Carriers with Helicopters."

†"Air Taxi Operators and Commercial Operators of Small Aircraft."

form the same functions as those in the air carrier aircraft. The most significant difference between the air carrier and general aviation aircraft influencing the design of their respective avionics is the typical annual utilization of the aircraft.

The utilization of general aviation aircraft is, on the average, an order of magnitude less than that of air carrier aircraft, a difference that leads to both economic and technical differences in the design of the avionics for the two segments of the civil fleet. For most general aviation aircraft an MTBF of 1,000 hours would limit the need for repair to only once about every four years.

CHAPTER THREE

SIGNIFICANCE OF RELIABILITY

3.1 OVERVIEW

One of the more significant differences frequently mentioned in comparisons between analog systems and digital systems is the greater reliability of digital systems. For this reason, it is appropriate to cite the activity of RTCA Special Committee 130, which was directed in 1977 to do the following:

a. Investigate the various means of determining and specifying reliability for electronic systems recommended by RTCA Minimum Performance Standards.

b. Assess the significance of specifying MTBR and MBTF for safety of flight electrical and electronic equipment.*

Some of the issues considered by Special Committee 130 were investigated in this study, but with emphasis on the unique characteristics of digital systems. In addition, any discussion of reliability invariably includes references to maintainability, integrity, and criticality of failure. It is difficult to separate these parameters when assessing their relevance to safety. Thus the following sections are intended to provide a general understanding of the concept of reliability as perceived by the air carrier and general aviation communities. The relationships of reliability to existing airworthiness standards, maintenance programs, integrity, and safety are also presented.

3.2 RELATIONSHIP BETWEEN RELIABILITY AND REGULATIONS

3.2.1 Air Carrier Regulations

FAR Part 121 requires that certain instruments and equipment -- considered dispatch-critical -- be in operable condition before the aircraft takes off. The reliability of dispatch-critical instruments and equipment is therefore crucial. It should be noted that in the context of FAR Part 121 reliability is associated with a requirement to maintain functional

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Airborne Electronics and Electrical Equipment Reliability, RTCA, Document No. DO-167, September 1977.

capability rather than to prevent equipment failure. The direct dependence of aircraft dispatch on the reliability of an individual unit can therefore be reduced through equipment redundancy. Because of differences in the air carriers' approaches to maintaining equipment and corresponding service reliability, varying levels of importance are attached to such reliability parameters as mean time between removals (MTBR) and mean time between failures (MTBF).

The airlines of the United States pioneered the use of formal, logic-based decision procedures for planning scheduled equipment maintenance. Their objective was to structure maintenance programs to minimize dispatch delays in a cost-effective manner. FAA Advisory Circular AC 121-22* provides guidelines to be used in the development and approval of initial maintenance and inspection requirements for air transport aircraft. As stated in AC 121-22, the purpose of a maintenance program is to maintain the inherent design levels of operating safety. The highest level of reliability and safety that can be expected from a unit, system, or aircraft is that level which is built into the unit, system, or aircraft and therefore inherent in the design.

AC 121-22 lists the following objectives of an efficient airline maintenance program:

(a) To prevent deterioration of the inherent design levels of reliability and operating safety of the aircraft, and (b) to accomplish this protection at the minimum practical costs.*

The airlines employ different techniques and procedures in establishing and complying with their avionics maintenance programs. The details of these programs and the records associated with them are considered proprietary to the companies. In addition, there is no single approach to reliability and maintainability that is superior to all others for all circumstances. The size of the aircraft fleet, the aircraft model, and the type and frequency of operations, as well as other considerations, all influence the structuring of the most appropriate maintenance program for a particular operator. There are, however, a number of maintenance practices that are common to most air carrier operations.

Historically, airline maintenance programs have included provisions for preventive maintenance. The tasks associated with preventive maintenance may include the following:

- Servicing
- Inspection
- Testing
- Calibration
- Replacement

*"Maintenance Review Board (MRB)," 12 January 1977.

The scheduling of these tasks is typically based on one of three philosophies:

- Hard Time Limit
- On Condition
- Condition Monitoring

A hard time limit establishes specific intervals within which maintenance tasks must be accomplished. These intervals apply to overhauls as well as replacement.

On-condition maintenance requires that a unit be periodically inspected or tested against some standard to verify that it can remain in service.

Condition monitoring is a process applied to equipment that is not subjected to a hard time limit or on-condition maintenance. Condition monitoring implies an environment in which the equipment "flies to failure," also referred to as "removal monitoring."

It is possible to develop additional maintenance tasks in a scheduled maintenance program that could improve reliability but would not be considered cost-effective -- as in situations in which operating safety is not affected by the failure condition being evaluated. The cost of the proposed maintenance task might exceed the value of the expected benefit, and it might be more appropriate to apply limited available resources to other areas that would provide a greater return on investment. In addition, it has been determined that "overall measures of reliability of complex components, such as the premature removal rate, usually are not functions of the age of these components."* The concept of predictable degradation of system components simply does not apply to the majority of current and future systems. In this environment, then, scheduled overhaul will not improve operating reliability.

3.2.2 General Aviation Regulations

The performance standards and specifications to which air carrier avionics must be certificated for FAR Part 121 operations are exemplified by Technical Standard Orders (TSOs). Demonstration of compliance with the TSO, or equivalent conformity, is mandatory for air carrier operations. Compliance with TSOs is not generally required for general aviation operations. The airworthiness of field installations of avionics is commonly approved by means of a simple Form 337 weight and balance report. Some of the more complex installations, particularly those including automatic flight controls, require Supplementary Type Certification (STC).

Requirements for maintaining records on the operation of general aviation aircraft are minimal. Avionics maintenance and repair work is usually performed without annotation of log time. Therefore, collection of representative MTBF data on general aviation avionics has not been practical.

*Ibid.

3.3 RELATIONSHIP BETWEEN RELIABILITY AND INTEGRITY

The integrity of a system is a measure of its ability to detect incorrect operation or failure. The objective is to assure that the system will not be used when it is not operating within its specified performance limits. Redundancy is one means of improving integrity. Redundancy can be provided at either the system or the subsystem level, with either identical or dissimilar system architecture, and in independent or interdependent modes of operations. Examples of interdependency include voting and averaging techniques. Self-test features incorporated in the system design also improve system integrity.

Most means of improving system integrity require an increase in the parts count associated with the functional capability being provided. As the parts count increases, so does the opportunity for part failure. Therefore, equipment reliability can diminish as a consequence of improving integrity. However, functional reliability -- the duration of uninterrupted satisfactory functional performance -- can be increased by redundancy.

The differences between equipment reliability and functional reliability are quite significant, but these differences are too frequently ignored when safety is being assessed on the basis of reliability.

3.4 RELATIONSHIP BETWEEN RELIABILITY AND SAFETY

The following excerpt from RTCA Document DO-167* is considered a satisfactory interpretation of operating safety in relation to system reliability:

> During the design process considerable attention is given to system and component failure effect analysis to ensure that failures that result in loss of function do not immediately jeopardize operating safety. In many cases, redundancy can cause the consequences of a first failure to be benign. In other cases, protective devices serve this purpose. Although it may not be possible to continue to dispatch the airplane without correcting the failure and although it may indeed be desirable to make an unscheduled landing after failure, the failure cannot be considered to have an immediate adverse effect upon operating safety. The inclusion of the word direct in the phrase 'direct adverse effect upon operating safety' means an effect which results from a specific failure mode occurring by itself and not in combination with other possible failure modes.

The certification process is intended to ensure that a transport category aircraft has very few failure modes which have a direct adverse effect upon operating safety.

**Airborne Electronics and Electrical Equipment Reliability*, September 1977.

CHAPTER FOUR

RELIABILITY RECORD KEEPING

4.1 AIR CARRIER RELIABILITY RECORDS

One of the objectives of efficient airline maintenance as defined in AC 121-22 is to "prevent deterioration of the inherent design levels of reliability." It is generally expected that system reliability will improve with time as the system matures. Trend analysis is an effective means of monitoring reliability so that a worsening condition can be easily and quickly identified.

Equipment users maintain records on the reliability of each equipment type. These records can include reference to a variety of actions that are related to reliability:

- Pilot reports
- Unit removals
- Unit failures
- Service information letters
- Service bulletins

The issuance of a pilot report does not necessarily lead to a removal. A corrective maintenance action such as reseating the unit may be sufficient to eliminate the problem indicated in the pilot report. Further, equipment removal, as reflected in MTBR, does not constitute failure. The reported failure of a removed unit is frequently unconfirmed, and this accounts for the disparity between MTBR and MTBF. Historical data indicate that, on the average, the number of removals is about twice the number of confirmed failures. There is disagreement about how to interpret a failure verification: Is it a verification of the failure that caused the problem reported by the pilot, or is it the identification of any failure? In addition, there are some questions concerning what constitutes a failure. The need to replace a component that is critical to the satisfactory performance of the unit definitely indicates the occurrence of a failure. But should an out-of-tolerance condition that causes degradation of performance, but can be corrected through a simple action such as turning an adjustment screw, be considered a failure? There are no standard answers to these questions. Each airline develops policies that, on the basis of

past experience and projected trends, it considers appropriate for assuring the efficiency and effectiveness of its operations.

The removal of a unit can be either scheduled or unscheduled. Scheduled removals are those accomplished to comply with a preventive maintenance program. Removals resulting from pilot reports, often referred to as premature removals, are unscheduled. MTBR can include the mean time between unscheduled removals (MTBUR). It is therefore difficult to compare MTBRs of different airlines without taking into account the differences in their maintenance practices. In this report, MTBR is considered equivalent to MTBUR, as it is by many air carriers.

Records are kept on all maintenance actions performed on a unit. The airlines closely monitor units that require maintenance more frequently than called for by a specified "alert level." The alert level used by an individual airline is based on both historical data and predictions related to the most effective and economic means of avoiding reliability deterioration. Once a unit's maintenance exceeds the alert level, the unit is entered into the formal monitoring process and is reported on each month. As a result of the increased visibility of the unit, emphasis is placed on identifying and correcting the problem that caused the alert level to be exceeded. There are a variety of explanations for why a unit is experiencing excessive removals, including improper diagnosis of a failure condition, intermittent failures, or a component failure.

Excessive removals that are due to improper diagnosis of failure conditions can be remedied through education and training. The cause of intermittent failures can be elusive, but it will eventually be discovered through application of a structured monitoring and diagnostic program. Component failures are relatively easy to trace and can be reported to the manufacturer. Following a preliminary investigation, the manufacturer may send a service information letter to all users of the unit in which a problem has been identified. The letter will describe the symptoms of the problem and provide some assurance that the problem will be solved. The manufacturer will issue a service bulletin to all users when a solution to the problem has been developed.

Removal rates and failure rates are based on 1,000 unit operating hours. The MTBR (or MTBF) is calculated by dividing the total unit operating hours accrued in a particular time period by the number of unit removals (or failures) that occurred during that same period. Unfortunately, there is no consensus on the appropriate basis for computing equipment operating hours. Among the alternatives are the use of gate-to-gate time, time from wheels-off to wheels-on, or engine operating hours, and the application of a multiplying factor to some form of log time (e.g., wheels-off to wheels-on) to obtain an estimate of equipment "on" time. The actual means of computing equipment operating hours is frequently negotiated by the equipment users and the manufacturer to establish the basis for warranty agreements.

Many of the air carriers participate in the exchange of reliability data by submitting data on particular systems for publication in *PLANE TALK*, the airline industry publication on avionics maintenance. Unfortunately, many of the data inputs are not directly comparable, since different airlines use different methods for computing and reporting system reliability. These differences must be taken into account if valid comparisons are to be made.

Although the failure records maintained by the air carriers do not follow a common format, the following parameters are considered typical:

- Airline part number (unique to each airline)
- Description of part (LRU, e.g., VHF NAV RECEIVER)
- Fleet code (e.g., 747)
- Quantity per aircraft (e.g., 2)
- Removal rates (parts 1,000 unit hours)
  - Current count (size of sample, e.g., 11)
  - Current month actual (e.g., 0.931)
  - Current month trend (e.g., 0.762)
  - Current control limit (e.g., 1.269)
  - Last 12 months (e.g., 0.514)
- MTBR - last 12 months (e.g., 1967)
- Failure rates (parts/1,000 unit hours)
  - Current count (e.g., 4)
  - Current month actual (e.g., 0.339)
  - Current month trend (e.g., 0.372)
  - Last 12 months (e.g. 0.304)
- MTBF - last 12 months (e.g., 3262)
- Failure rate/removal rate - last 12 months (e.g., 0.591)

The Avionics Maintenance Conference (AMC), a coalition of representatives of air transport operators, equipment manufacturers, airframe manufacturers, and regulatory and support organizations, provides an open forum to discuss avionics maintenance problems. One of the AMC task groups is developing an upgraded reliability reporting program. As it does now, *PLANE TALK* will provide the means of disseminating reliability data throughout the industry. The proposed program will define an initial baseline of participating operators and the equipment on which each participating operator will provide data. A standard format will be used for data submission, and it will require both MTBUR *and* MTBF. The proposed schedule for implementing this upgraded reporting program lists 31 August 1982 as the date on which proposed data forms will be submitted to operators for their review. The first report under the new program is scheduled for publication in *PLANE TALK* in January 1983.

4.2 GENERAL AVIATION RELIABILITY RECORDS

A review of the entire spectrum of general aviation operators reveals a lack of records that would permit a comprehensive evaluation of avionics reliability. There are, however, particular groups within the general aviation community that maintain detailed records. Most operators of corporate fleets of heavy aircraft have an aviation department that documents maintenance and cost details. Commuter operators also maintain detailed records, whether they run their own avionics maintenance shop or employ an independent certificated repair agency. However, the avionics reliability studies performed on the basis of these available records have been structured primarily for specific product evaluations.

The element of the industry most highly motivated to collect avionics reliability data is the avionics manufacturer. Whether the market is air carrier or general aviation, MTBF is a powerful selling tool, with significance to both the avionics user and the manufacturer. If for any reason an avionics manufacturer introduces a product that is perceived as unreliable by potential customers, he is faced with a reduction in sales revenue and an increase in warranty or remanufacturing expense. Thus, to avoid these economic problems, in the past decade manufacturers have used a number of data collection and data processing techniques to measure the reliability of products when they are introduced.

Product reliability can be determined in several ways:

- The theoretical MTBF can be calculated from the parts count and the other data recorded during the design process.
- A demonstrated MTBF can be produced by subjecting a limited preproduction batch of the product to a complex series of stress tests.
- The warranty claims submitted during the warranty period, typically the first year of installation and service, can be used in conjunction with the operator-reported utilization of the aircraft to establish a reasonably credible MTBF.

CHAPTER FIVE

DATA COLLECTION

5.1 DATA COLLECTION METHOD

One of the primary objectives of the study was to identify how widely digital avionics and flight control systems are used in currently operational aircraft. Careful selection of appropriate air carriers provided a well distributed sampling of all relevant air transport aircraft.

The May 1981 publication of *Air Transport World* presented a breakdown of the world air transport fleet based on 1980 data. Close examination of the fleet data indicated a dominance of the six aircraft types listed in Table 5-1. Since they constituted 77.7 percent of the fleet identified in *Air Transport World,* it was concluded that an investigation of the types and quantities of digital avionics used in those aircraft would provide a reasonable indication of total fleet utilization of digital systems. The aircraft listed in Table 5-1 are manufactured in the United States. It is recognized that other countries manufacture large numbers of aircraft. However, foreign-manufactured aircraft represent only a small fraction of the total United States fleet, and any digital system installations are most likely duplicated on the six aircraft selected.

Table 5-1. COMPOSITION OF AIR TRANSPORT AIRCRAFT FLEET

Aircraft Type	Number in Fleet	Percentage of Fleet
B-747	449	9.2
B-737	568	11.6
B-727	1,465	30.0
DC-10	312	6.4
DC-9	826	16.9
L-1011	178	3.6
Total	3,798	77.7

Having identified the air transport aircraft models of interest, the distribution of those models among selected air carriers was examined. Table 5-2 shows that distribution. The objective of this exercise was to select a group of airlines whose cumulative fleet totals of a particular aircraft model represented at least 15 percent of the total number of that model in use throughout the world. With the exception of the DC-9, that objective was satisfied by the airlines listed in the table.

Table 5-2. COMPOSITION OF AIR CARRIER FLEETS

Airline	Aircraft Quantities					
	B-747	B-737	B-727	DC-10	DC-9	L-1011
American	14	--	179	34	--	--
Piedmont	--	42	8	--	--	--
Eastern	--	--	142	--	75	29
United	18	48	173	42	--	--
Delta	--	--	126	--	38	35
TWA	18	--	90	--	--	32
Northwest	29	--	66	22	--	--
Subtotal	79	90	784	98	113	96
World Fleet Total	449	568	1,465	312	826	178
Percentage of Fleet	17.6	15.8	53.5	31.4	13.7	53.9

From the equipment lists provided by the airlines, a composite listing was prepared and the equipments subdivided into five groups in accordance with the classification criteria. The five groups were:

- Navigation
- Flight Instruments
- Flight Data
- Autopilot and Flight Controls
- Communications

Commonality of responses was used to establish the basis for a first-order definition of the word *digital*. Systems considered digital by one airline or manufacturer and not considered digital by another were evaluated in the light of their applications to determine why they were considered by some industry representatives to be uniquely different from other digital

systems. This process of cross-correlation and comparative analysis led to the development of categories of digital systems according to operational application and technical design. These categories provided a means of directing subsequent data collection.

The particular application of a digital system had a significant influence on the extent to which that system was considered relevant to the study. Systems approved for use as a consequence of certification of the airframe do not have as much visibility as systems that are certified independently on the basis of unique functional capability. Problems associated with a particular system can be better analyzed when abundant data are available to permit tracing the history and resolution of the problems. A problem was considered relevant to this study only when it was identified as being peculiar to the use of digital systems. The function of the system in which a problem occurred was not of primary concern unless there was a direct relationship between the function and the problem. Emphasis was placed on identifying those systems which highlight the performance characteristics of digital systems rather than on identifying every digital system installed on an aircraft.

5.2 MTBR AND MTBF TABLES

The following subsections provide the reliability data obtained on both air carrier and general aviation digital systems. To preserve narrative continuity, Tables 5-3 through 5-10 are presented at the end of this chapter.

5.2.1 Air Carrier Data

Tables 5-3 through 5-10 present the reliability data collected on air carrier avionics in the form of MTBR and MTBF. The tables are organized by major system categories, as described in the following sections. The terms used in the tables are defined as follows:

- Unit I.D. Number - To maintain the confidentiality of the data, an identity number was assigned to each model investigated rather than use the manufacturer's model number. The letter prefixes represent major categories: N for navigation equipment, I for flight instruments, C for flight controls, and M for miscellaneous equipments.
- Analog or Digital - An A or D is shown to indicate a classification of either analog or digital for the unit listed.
- Operating Hours - The value shown for operating hours is the total of the operating hours reported from all sources. For the MTBF tables, the operating hours reflect only those sources providing MTBF data.

- <u>Number of Removals or Failures</u> - In Tables 5-3, 5-5, 5-7, and 5-9, the total number of removals is shown. In Tables 5-4, 5-6, 5-8, and 5-10, the total number of reported failures is shown.
- <u>Lowest and Highest Reported Values</u> - The lowest and highest reliability values reported are included to provide an indication of the variability of the data and to reflect extr mes reported from the various sources.
- <u>Average Value</u> - The average reliability value is obtained by dividing the total operating hours by the total removals or total failures.

5.2.1.1 Navigation Equipments

More than 30 models were investigated as possible digital units. As shown in Table 5-3, 19 digital models were identified in the navigation category. Some of the models that were found to be analog are presented in Table 5-3 for comparison.

As shown in Table 5-4, MTBF data were reported for only 13 of the 19 identified models of digital navigation systems.

5.2.1.2 Flight Instruments

Tables 5-5 and 5-6 address the flight instrument category. As shown in the tables, a large number of the models investigated were considered to be analog. MTBR data were received on only 16 of 19 digital models identified. MTBF data were received on 8 digital models.

5.2.1.3 Flight Controls

Tables 5-7 and 5-8 address the flight control category. Only two models were identified as digital. MTBR data were reported for both digital models, and MTBF data were reported for only one.

5.2.1.4 Miscellaneous Equipments

Tables 5-9 and 5-10 present the data collected for 18 digital models that were not included in the other five defined categories. M1 and M2 are representative of digital communication units. M3 through M18 are models that have recently been developed; they include flight instruments and electronic engine controls. The average values shown for M3 through M18 are based on estimates or preliminary tests rather than on airline experience.

5.2.2 General Aviation Data

The general aviation community comprises a multitude of aircraft types, ranging in complexity from gliders and single-engine piston aircraft to air transport category aircraft. General aviation aircraft are used in air taxi, air cargo, and agricultural operations, and in business, research, and personal flying. The equipment flown on general aviation

aircraft can be divided into three major categories: (1) equipment built in accordance with ARINC characteristics, (2) equipment designed for high-performance general aviation aircraft, and (3) equipment designed for low-performance general aviation aircraft.

Discussions with representatives of avionics manufacturers indicate that the introduction of digital avionics into the general aviation market has been quite limited. MTBF data for three types of general aviation digital (microprocessor-based) avionics units are as follows:

Unit	Calculated MTBF (Hours)	Demonstrated MTBF (Hours)	Field MTBF* (Hours)	Units in Sample
DME	2,200	1,700	2,000	2,000
NAV	1,370	2,150	1,740	850
COM	1,670	920	1,550	1,160

The MTBF calculation was based on parts count and design data. The demonstrated MTBF was determined on the basis of stress testing of a limited sample of preproduction units. Analysis of warranty failure-claim data, assuming an average utilization rate of 262 hours per year, produced the field MTBF values.

The warranty failure claim data and the average utilization rate of 262 hours per year were used to calculate the field reliability of nonmicroprocessor-based avionics:

Unit	Field MTBF (Hours)
DME	600
NAV	500
COM	750

No calculated or demonstrated MTBF data were available for these systems. The number of units in the nondigital avionics sample was somewhat larger than the number in the digital sample.

*During investigation of the reported failures of digital units, it was found that approximately 40 percent of the reported malfunctions were installation-related.

Table 5-3. MTBR VALUES FOR NAVIGATION EQUIPMENT						
I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Removals	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
VOR/ILS						
N1	D	609	303	723	9,090	2,009
N2	D	237	193	1,225	1,225	1,225
N3	A	544	245	1,372	1,372	2,222
N4	A	1,046	726	1,064	1,695	1,372
N5	A	263	71	3,703	3,703	3,703
N6	D	3,297	2,835	885	1,896	1,163
Omega						
N7	D	743	963	348	1,337	771
INS/NAV						
N8	D	18	104	160	213	178
N9	D	5,873	1,600	725	3,778	3,670
N10	D	430	549	607	1,626	783
N11	D	465	397	864	2,000	1,171
INS/CDU						
N12	D	198	118	1,613	1,818	1,678
ATC Transponders						
N13	D	304	47	1,887	10,749	6,476
N14	D	1,343	481	644	10,383	2,792
N15	D	1,226	393	2,024	4,166	3,119
N16	D	352	168	1,557	3,389	2,095
DME Interrogator						
N17	D	819	533	1,010	6,747	1,536
N18	D	1,832	994	1,003	16,439	1,843
N19	D	938	301	2,083	4,762	3,116
N20	D	141	76	1,683	2,207	1,865
Radio Altimeter						
N21	D	749	395	1,492	2,597	1,897
N22	D	1,069	616	1,117	2,272	1,735
Conventional Altimeter						
N23	A	[illegible]	[illegible]	3,846	3,846	3,846

Table 5-4. MTBF VALUES FOR NAVIGATION EQUIPMENT

I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Failures	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
VOR/ILS						
N1	D	285	72	3,404	5,263	3,958
N2	D	237	112	2,111	2,111	2,111
Omega						
N7	D	267	197	1,109	1,600	1,355
INS/NAV						
N9	D	777	66	1,160	4,545	2,354
N10	D	223	269	666	2,449	829
ATC Transponder						
N13	D	248	31	3,704	10,749	8,000
N14	D	623	68	1,645	31,150	9,161
N15	D	348	80	3,472	5,376	4,350
N16	D	352	168	2,816	7,194	3,826
DME Interrogator						
N17	D	104	14	7,122	7,122	7,122
N18	D	1,238	285	2,717	11,477	4,343
N20	D	141	40	2,710	6,172	3,525
Radio Altimeter						
N21	D	542	132	3,367	6,756	4,106

I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Removals	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
Ground Proximity Warning System						
I1	D	4,127	2,309	885	3,846	1,787
I2	D	2,605	505	3,891	8,849	5,158
I3	D	800	312	1,572	14,493	2,564
I4	D	490	116	2,100	20,334	4,224
Air Data Computers						
I5	D	279	52	2,500	8,169	5,365
I6	D	369	220	1,431	2,081	1,677
I7	D	49	45	816	2,369	1,088
I8	A	514	365	844	3,226	1,408
I9	A	410	426	744	5,882	962
I10	A	309	305	853	2,678	1,013
I11	A	956	465	1,219	11,038	2,056
I12	A	62	75	825	825	825
I13	A	170	177	961	961	961
I14	A	243	192	1,266	1,266	1,266
I15	A	317	254	1,250	1,250	1,250
I16	A	54	55	975	975	975
Thrust Rating Computer						
I17	D	564	283	1,992	1,992	1,992
I18	D	4,213	2,691	1,565	1,565	1,565
Stall Warning Computer						
I19	D	237	19	12,383	12,383	12,383
I20	A	8,480	2,288	3,610	9,803	3,706
Mach Airspeed Indicator						
I21	A	127	23	5,555	5,555	5,555
I22	A	403	208	1,718	2,040	1,937
I23	A	1,025	41	25,000	25,000	25,000
I24	A	170	70	2,439	2,439	2,439
Flight Data Recorders						
I25	D	2,632	1,617	1,041	9,090	1,627
I26	D	198	48	3,861	4,549	4,125
I27	D	141	134	1,051	1,066	1,052
I28	D	576	186	2,036	3,311	3,091
Flight Data Acquisition Units						
I29	D	108	21	7,092	10,666	9,4[illegible]8
I30	D	[illegible]	31	2,577	2,577	2,577

Table 5-5. MTBR VALUES FOR FLIGHT INSTRUMENTS

Table 5-6. MTBF VALUES FOR FLIGHT INSTRUMENTS						
I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Failures	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
Ground Proximity Warning System						
I2	D	708	34	16,393	76,923	20,823
I4	D	490	72	3,734	27,087	6,805
Air Data Computers						
I5	D	246	15	6,060	25,528	16,400
I9	A	114	53	1,336	5,882	2,151
I10	A	309	219	1,411	1,411	1,411
I11	A	672	186	1,250	13,556	3,612
I12	A	62	37	1,672	1,672	1,672
I16	A	54	34	1,579	1,579	1,579
Stall Warning Computers						
I19	D	237	10	24,765	24,765	24,765
I20	A	215	32	5,319	21,276	6,718
Mach Airspeed Indicator						
I22	A	142	63	2,252	2,293	2,254
Flight Data Recorders						
I26	D	183	29	6,066	6,498	6,310
I27	D	141	63	2,222	2,293	2,238
I28	D	575	186	2,036	3,875	3,639
Flight Data Acquisition Unit						
I30	D	80	21	3,802	3,802	3,802

Table 5-7. MTBR VALUES FOR FLIGHT CONTROLS

I.D. Number	Analog of Digital	Operating Hours (Multiply by 1,000)	Number of Removals	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
Yaw Damper						
C1	D	102	17	6,007	6,007	6,007
C2	A	126	38	3,333	3,333	3,333
Pitch Computer						
C3	A	152	152	998	998	998
C4	A	566	22	25,641	27,027	25,727
Roll Computer						
C5	A	152	115	1,319	1,319	1,319
C6	A	566	32	10,869	28,571	17,687
Speed Control Computer						
C7	A	80	27	2,958	2,958	2,958
C8	A	222	65	3,424	3,424	3,424
Flight Control Systems						
C10	A	80	172	464	464	464
C11	A	65	47	1,393	1,394	1,394
C12	D	110	105	623	2,037	1,047

Table 5-8. MTBF VALUES FOR FLIGHT CONTROLS

I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Removals	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
Yaw Damper						
C1	D	126	9	11,346	11,346	11,346
Pitch Computer						
C3	A	152	75	2,024	2,024	2,024
C4	A	566	17	29,411	38,461	33,294
Roll Computer						
C5	A	152	55	2,762	2,762	2,762
C6	A	566	26	14,084	33,333	21,769
Speed Control Computer						
C7	A	80	17	4,705	4,705	4,705
C8	A	222	28	7,936	7,936	7,936
Flight Control Systems						
C10	A	80	51	1,567	1,567	1,567
C11	A	65	22	2,976	2,976	2,976

Table 5-9. MTBR VALUES FOR MISCELLANEOUS EQUIPMENTS

I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Removals	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
Communications						
M1	D	862	847	390	1,474	1,018
M2	D	705	503	583	2,500	1,401
Flight Instruments						
M3	D	NR*	NR	NR	NR	830
M4	D	NR	NR	NR	NR	2,250
M5	D	NR	NR	NR	NR	6,400
M6	D	NR	NR	NR	NR	1,500
M7	D	NR	NR	NR	NR	4,000
M8	D	NR	NR	NR	NR	5,400
M9	D	NR	NR	NR	NR	3,800
M10	D	NR	NR	NR	NR	8,900
M11	D	NR	NR	NR	NR	2,250
M12	D	NR	NR	NR	NR	3,500
M13	D	NR	NR	NR	NR	2,700
M14	D	NR	NR	NR	NR	735
M15	D	NR	NR	NR	NR	16,000
Engine Controls						
M16	D	NR	NR	NR	NR	2,500
M17	D	NR	NR	NR	NR	3,100
M18	D	NR	NR	NR	NR	25,000

*NR - Value not reported.

Table 5-10. MTBF VALUES FOR MISCELLANEOUS EQUIPMENTS

I.D. Number	Analog or Digital	Operating Hours (Multiply by 1,000)	Number of Failures	Lowest Reported Value (Hours)	Highest Reported Value (Hours)	Average Value (Hours)
Communications						
M1	D	226	51	1,299	6,771	4,431
M2	D	91	106	632	1,070	858
Flight Instruments						
M3	D	NR*	NR	NR	NR	1,500
M4	D	NR	NR	NR	NR	4,500
M5	D	NR	NR	NR	NR	9,100
M6	D	NR	NR	NR	NR	3,140
M7	D	NR	NR	NR	NR	8,396
M8	D	NR	NR	NR	NR	8,100
M9	D	NR	NR	NR	NR	5,100
M10	D	NR	NR	NR	NR	14,900
M11	D	NR	NR	NR	NR	5,000
M12	D	NR	NR	NR	NR	8,000
M13	D	NR	NR	NR	NR	8,000
M14	D	NR	NR	NR	NR	1,358
M15	D	NR	NR	NR	NR	17,700
Engine Controls						
M16	D	NR	NR	NR	NR	2,800
M17	D	NR	NR	NR	NR	3,400
M18	D	NR	NR	NR	NR	30,000

*NR - Value not reported.

CHAPTER SIX

DATA ANALYSIS

6.1 OVERVIEW

This chapter presents analyses of the data described in Chapter Five. The analyses focus on identifying the relationships between unit removal rates and the following variables of interest:

- System category
- Failure rate
- Design
  - Analog
  - Digital
- Application

6.2 RELIABILITY VS. SYSTEM CATEGORY

Table 6-1 presents calculated MTBR values for selected groups of digital units. The units are grouped by functional similarity but may not be functionally interchangeable. The values shown are based on the data presented in Chapter Five.

Figure 6-1 graphically summarizes the reliability data presented in Table 6-1 on various types of air carrier digital avionics in terms of MTBR. The length of the bars shown in Figure 6-1 is determined by the group MTBR. The width of the bars is proportional to the operating hours from which the group MTBR was obtained. For example, the MTBR of flight recorders is shown as nearly 1,800 hours; the width of the bar indicates that a total of 3.5 million hours is represented in the sample. Figure 6-1 suggests that a 2,000 hour MTBR value is generally achievable by a digital design.

Comparison of the group MTBRs with the individual model MTBRs shown in the tables of Chapter Five shows the averaging effect of grouping data. The Chapter Five tables show MTBR values that are much higher and much lower than 2,000 hours. The wide range in values is due to the differences in design and in individual maintenance practices.

Table 6-1. RELIABILITY OF DIGITAL EQUIPMENT GROUPS						
Equipment Group	Models In Group	Operating Hours (Multiply by 1,000)	Number of Removals	Lowest Individual MTBR (Hours)	Highest Individual MTBR (Hours)	Group Average MTBR (Hours)
Navigation						
VOR/ILS	N1, N2, N6	4,143	3,331	1,225	2,009	1,243
INS	N8*, N9, N10, N11	6,786	2,650	178	3,670	2,560
INS/CDU	N12	198	118	1,613	1,818	1,678
Transponders	N13, N14, N15, N16	3,225	1,089	2,095	6,476	2,961
DME Interrogator	N17, N18, N19, N20	3,730	1,904	1,536	3,116	1,945
Radio Altimeter	N21, N22	1,818	1,011	1,735	1,897	1,798
Flight Instruments						
Ground Proximity	I1, I2, I3, I4	8,022	3,242	1,787	5,158	2,474
Air Data Computers						
Digital	I5, I6	648	272	1,677	5,365	2,382
Analog	I8, I9, I10, I11, I13, I14, I15	2,919	2,184	961	2,056	1,336
Thrust Rating Computers	I17, I18	4,777	2,974	1,562	1,992	1,606
Flight Recorders	I25, I26, I27, I28	3,546	1,985	1,052	4,125	1,786
Flight Controls						
	C1	102	17	6,007	6,007	6,007
Communications						
	M1 M2	862 705	847 503	390 583	1,474 2,500	1,018 1,401

*N8 had an MTBR of 178, with 104,000 operating hours. The low reliability could indicate a poor design compared with other INS units, or it could indicate a reporting error.

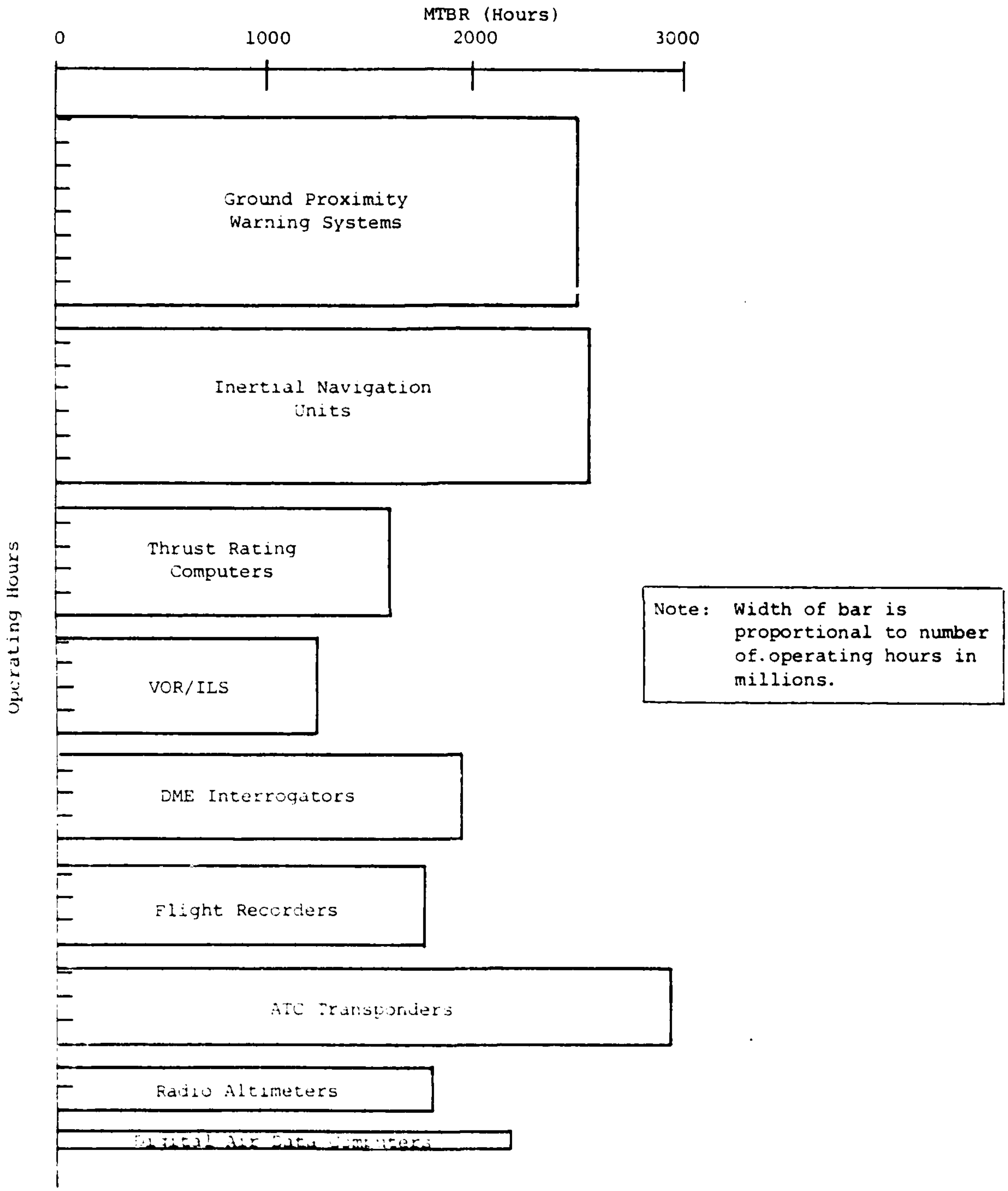

Figure 6-1. SUMMARY OF RELIABILITY DATA FOR DIGITAL SYSTEMS

A similar presentation based on MTBF values was not included, because the lack of sufficient MTBF data prevents valid interpretation.

6.3 REMOVALS VS. FAILURES

The confirmed-failure ratio is obtained by dividing the MTBR value by the MTBF value. The ratio is often used by airlines and manufacturers as an indication of whether a model has mechanical or operator problems. A low ratio may indicate either that removals are due to operator error or that the failure condition cannot be successfully detected. If an airline experiences a low MTBR and a low confirmed-failure ratio (far more removals than failures), then operating procedures are checked first. In the case of a low MTBR and a high confirmed-failure ratio (frequent removals, generally due to failures), the repair records are reviewed and an equipment modification may be recommended.

Table 6-2 lists all of the digital units investigated for which data on both MTBR and MTBF were available. The identification numbers permit direct correlation with the data tables in Chapter Five.

Table 6-2. CONFIRMED-FAILURE RATIO OF DIGITAL UNITS

I.D. Number	MTBR Hours	MTBF Hours	Ratio
N1	2,009	3,958	0.51
N2	1,225	2,111	0.58
N7	771	1,355	0.57
N10	783	829	0.94
N14	2,792	9,161	0.30
N15	3,119	4,350	0.72
N16	2,095	3,826	0.55
N17	1,536	7,122	0.22
N18	1,843	4,343	0.42
N20	1,865	3,525	0.53
N21	1,897	4,106	0.46
I2	5,158	20,823	0.25
I4	4,224	6,805	0.62
I5	5,365	16,400	0.33
I26	4,125	6,310	0.65
I27	1,052	2,127	0.49
I28	3,091	3,639	0.85
C1	6,007	11,346	0.53
M1	1,018	4,431	0.23
		Geometric Mean =	0.475

The geometric mean of all ratios shown in Table 6-2 is 0.475. This is close to the 0.50 confirmed-failure ratio frequently cited in industry, which indicates that there are, on the average, twice as many removals as confirmed failures.

6.4 ANALOG VS. DIGITAL

Figures 6-2 and 6-3 compare analog reliability with digital reliability in terms of the MTBR and MTBF of air data computers. The demonstrated reliability of the digital air data computer identified as Model I5 is significantly better than that of all other analog and digital models represented. The MTBRs of the other two digital models are similar to the MTBRs of the analog models. Although the data do not provide evidence that all digital units have superior reliability in comparison with analog units that perform the same function, the reliability of Model I5 does indicate that significant reliability improvements are possible.

6.5 APPLICATIONS ANALYSIS

The various models of Ground Proximity Warning Systems (GPWS) are all comparable in design. Each uses analog inputs and digital processing, and the same model can be used in a variety of aircraft.

Figure 6-4 graphically illustrates the data of Table 5-5 for four GPWS models. The range of values implies that functional capability is only one factor affecting the MTBR values. If the MTBF values had been more nearly equal, it might have been concluded that units of similar function could be expected to have similar MTBR values.

Figure 6-5 presents the MTBR values for the composite of the four GPWS models by airframe. When MTBR values of individual GPWS models are compared, no airframe can be said to perform best consistently.

6.6 SUMMARY OF ANALYSES

The analyses presented in this chapter are representative examples. Air data computers and ground proximity warning systems were used examples because sufficient data were available for them. Presentations based on other digital systems would have shown similar results.

The available data on the reliability of air carrier avionics indicate that digital systems are capable of performing more reliably than comparable analog systems. Average MTBR values of 2,000 hours and MTBF values of 4,000 hours are expected for most digital systems.

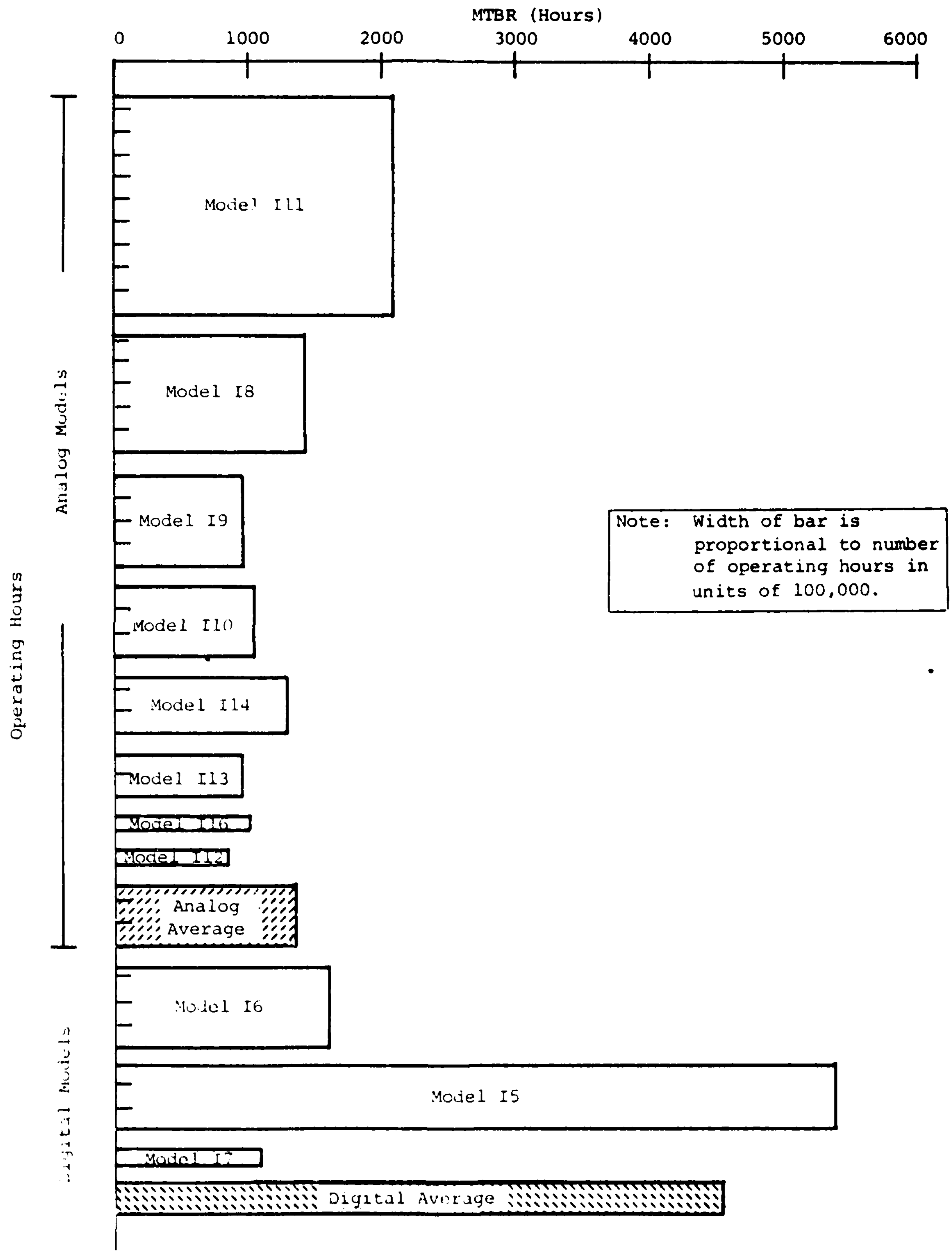

Figure 6-2. MTBR FOR AIR DATA COMPUTERS

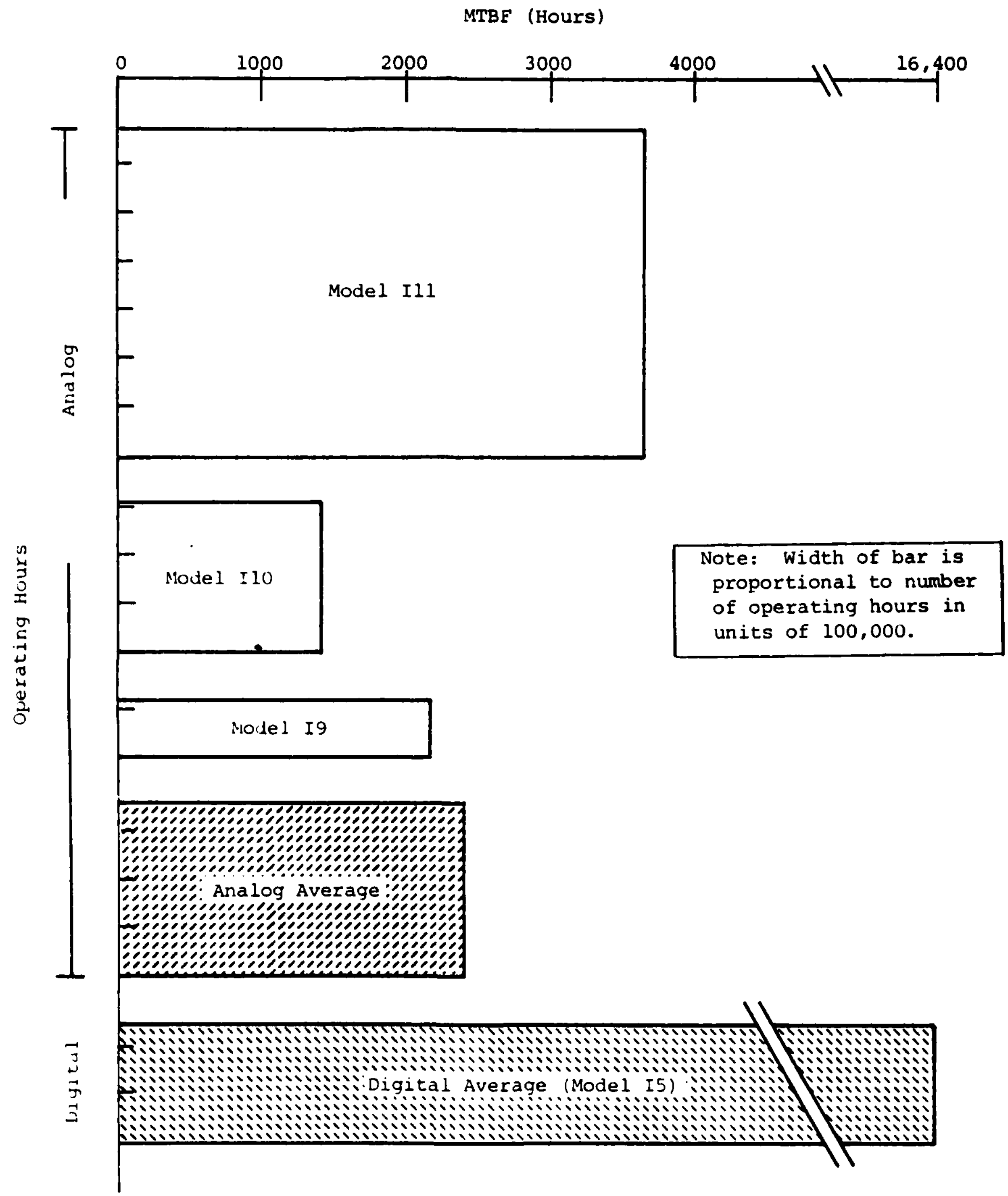

Figure 6-3. MTBF FOR AIR DATA COMPUTERS

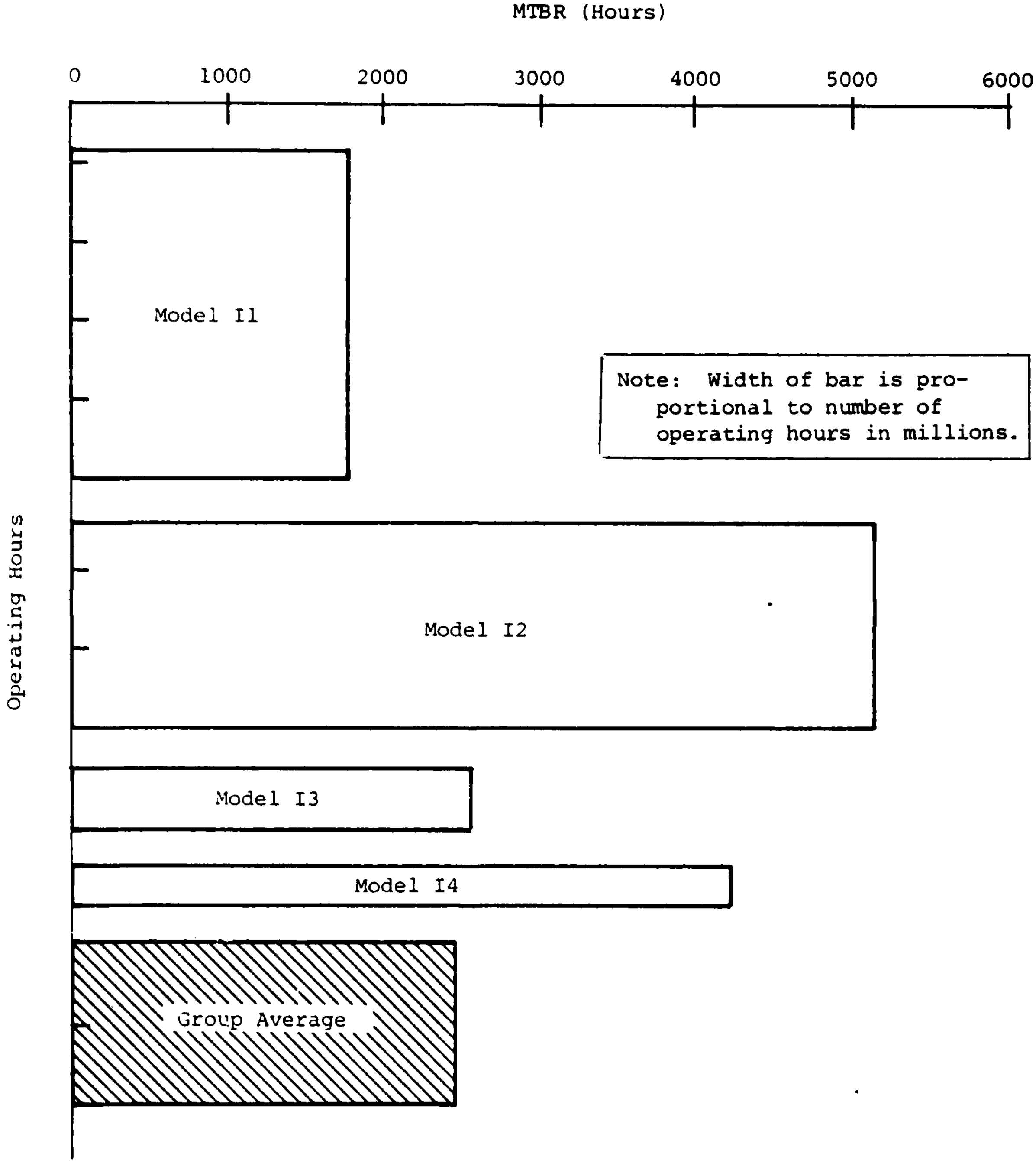

Figure 6-4. MTBR FOR GROUND PROXIMITY WARNING SYSTEMS

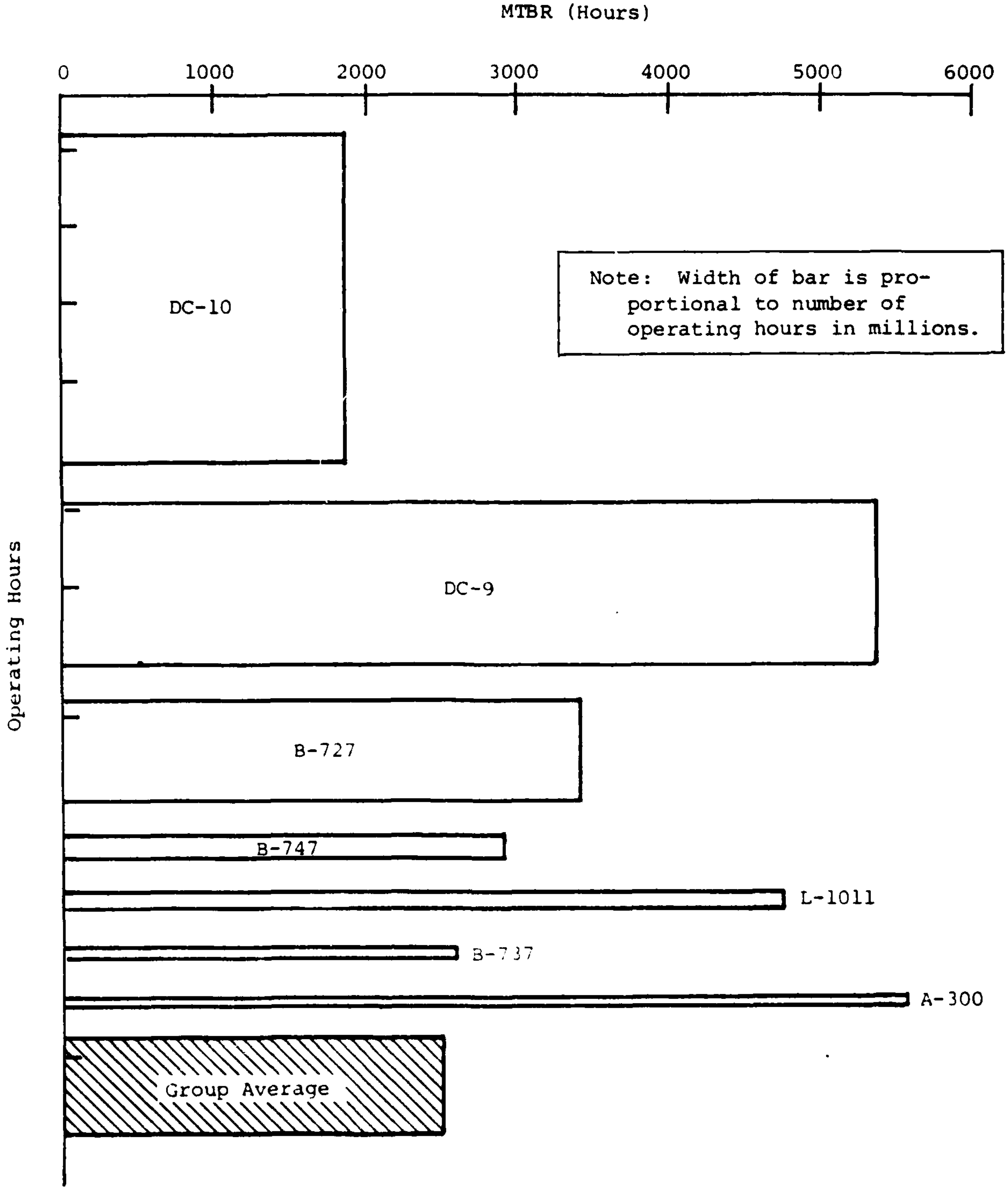

Figure 6-5. COMPOSITE OF GPWS RELIABILITY BY AIRFRAME

CHAPTER SEVEN

DISCUSSION

7.1 OVERVIEW

Chapters Five and Six addressed the objective data collected in this study. In addition to the objective data, valuable subjective information was gathered during discussions with airline and manufacturer representatives. This chapter presents the subjective information, with references to objective data where applicable.

7.2 DIGITAL EXPANSION

Digital equipments have been introduced to the airframes through both retrofit and initial installations. The airframes generally called "older" and "narrow body" -- B-707, B-727, B-737, DC-8, and DC-9 -- did not originally have digital equipment. Digital equipments in these airframes were retrofitted with modular boxes that do not require functional integration with the airframe, such as navigation units, ATC transponders, and ground proximity warning systems. In some cases, major retrofit programs modified airframes by incorporating digital systems. The DC-9-80 is an example of an extensive digital retrofit. Wide-body aircraft such as the DC-10, B-747, L-1011, and A-300 contain some integrated digital flight controls and flight instruments in addition to the previously mentioned modular boxes.

All of the units identified in the equipment lists presented in Section 5.2 are currently operational. The responsibility for implementation, use, and maintenance of those systems is jointly shared by manufacturers and users. Airframe manufacturers did not participate in this activity to any significant degree. However, the introduction of integrated cockpit system architecture as an integral element of the original airframe package has shifted a significant amount of integration responsibility to the airframe manufacturers. In their newly emerging role as system integrators, airframe manufacturers are concerned with the performance characteristics of all units that will constitute the integrated avionics suites to be incorporated in new aircraft such as the B-757 and B-767.

Table 7-1 lists the planned B-757 and B-767 equipments that include a microprocessor. The list shows that all of the system categories investigated in this study will be digital in the future.

Table 7-1. B-757/767 SYSTEMS USING MICROPROCESSOR-BASED DIGITAL SYSTEMS

Fuel Quantity System	VOR	VOR/DME Control Panel
ECS-Air Sypply System	Transponder	Audio Accessory Unit
Pack Temperature Controller	Autopilot	Yaw Damper Computer
Zone Temperature Controller	Electronic Flight Instruments	Passenger Entertainment and Service
Cabin Pressure Controller	Electronic Indication and Crew Alerting System	Digital Flight Data Acquisition Unit
Standby Pack Controller	ILS Receiver	Electronic Clock
ECS Flow Sensor	RMI	Flight Management System
Generator Control Unit Bus Protection Control Unit	ADF Receiver	Mach Indicator
Windshield Heat Control	DME Interrogator	Vertical Speed Indicator
Overheat Control System	Radio Altimeter Transceiver	Altimeter Control Panel
Auxiliary Power Unit Control	VHF Transceiver	Ground Proximity Computer
Engine Vibration Monitor	HF Transceiver	Inertial Reference System
Power Management Computer	Weather Radar System	Pitch Augmentation Control System
Engine Electronic Control	Altitude Alert Panel	Thrust Management System
Master Warning Panel	Aural Warning Panel	Stall Warning Panel
	ILS Control Panel	

7.3 RELIABILITY REPORTING FORMATS

As mentioned in Chapter Four, the reliability reporting formats used by airlines and manufacturers are designed in accordance with individual operational and management practices. There are variations that affect the accessibility and traceability of records. For example, it is a common practice to assign an airline part number in addition to the manufacturer's part number. If the airline records are organized by airline part number, it may be difficult to correlate manufacturer part numbers with airline part numbers. Another variation is in the reporting periods. Almost all airlines have current-month data. However, other periods may be tracked, such as each month's average, three-month average, six-month average, and twelve-month average. Airlines may not report on all equipments. Because of the large parts inventory, an airline may monitor only those systems whose reliability levels trigger a threshold for concern. Thus if a unit is maintaining its expected level of performance, it will not be included in the monthly report.

7.4 UNIT RELIABILITY AND OPERATING HOURS

MTBR and MTBF values are calculated from the number of operating hours between removals or failures of an individual unit. However, the determination of operating hours varies widely. The most frequently recorded operating time is that of the airframe, which is usually referred to as "wheels up to wheels down." Since the avionics units are often operated much longer than the actual flight times, a multiplication factor is introduced to compensate for the difference. The factor varies among airlines, manufacturers, and airports, and ranges from 1.0 to 2.3. That large a variation in the basic calculation of MTBR and MTBF can distort any comparisons of performance.

Operating hours are also important in assessing the performance of a design. New designs usually have low MTBR and MTBF values when first put into service. As experience with the design grows, as expressed by accumulated operating hours, design errors are found and corrected. MTBR and MTBF values then increase until they reach a mature, or consistent, rate. Design maturity is usually reached after six months to a year of fleet operation.

7.5 MTBF RECORDS

Airlines rely more on MTBR data than on MTBF data. In this study, airlines reported MTBF values much less frequently than MTBR values. The major reason for the emphasis on removals is the cost to the airline for removals regardless of whether any failure is detected.

The fact that removed units may be sent to other than airline-owned repair shops makes the failure records difficult to trace. Figure 7-1 illustrates the typical process followed for unit removal, repair, and replacement.

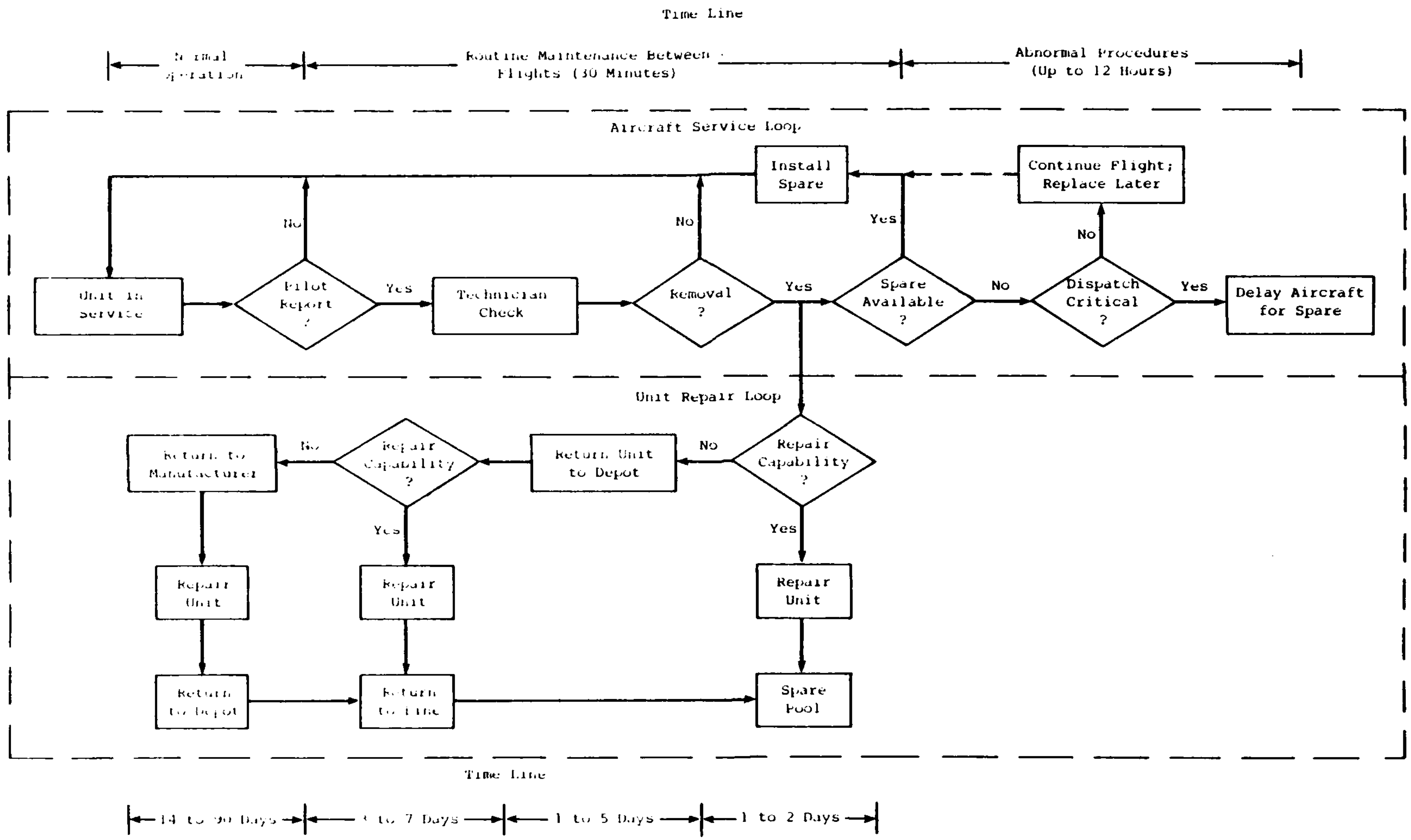

Figure 7-1. TYPICAL PROCEDURAL FLOW FOR AIRLINE UNIT REMOVAL, REPAIR, AND REPLACEMENT

Avionics manufacturers prefer tracking MTBF rather than MTBR. This preference is due to the perception that the failure rate indicates the quality of the design but the removal rate may be affected by training and maintenance practices.

7.6 RELIABILITY OF MULTIPLE-UNIT SYSTEMS

The reliability of a system composed of more than one line replaceable unit (LRU) must be related to the probability that all units will be available. For example, a navigation unit may have a receiver unit and a separate control display unit (CDU). A failure of either unit removes the system from service.

7.7 DIGITAL PERFORMANCE VS. ANALOG PERFORMANCE

In general, the digital designs are not one-to-one conversions from analog designs. When a previously analog function is provided by a digital design, additional functions and features are often included. One of the most important of these features is built-in test (BIT). BIT was intended to assist in the detection and correction of failures in order to improve maintainability. The MTBR and MTBF values presented in Chapter Five indicate that digital systems can offer better reliability than analog systems. However, the ratio of MTBF to MTBR for digital systems approximates the existing ratio for analog systems -- an average of two removals for each confirmed failure.

7.8 FAILURE MECHANISMS

Damage resulting from heat and power transients remain a major cause of failure in avionics. Digital designs minimize power consumption, thereby reducing the level of heat generated. The binary switching logic in digital designs can be, however, more susceptible to the effects of power transients.

7.9 RELIABILITY AND CRITICALITY

The MTBR and MTBF values are not clearly related to the criticality of service, primarily because many removals and failures do not involve a critical function. Reliability values are associated with the frequency rather than the severity of failures. For example, if an LED display had a failed segment, it would be removed and repaired. However, the pilot may have been able to use the display in spite of the failure. Another example is the loss of secondary functions. Some digital units may include optional accessories or features that are not critical. Therefore, a removal and repair of a noncritical function could affect the reported reliability of a unit without affecting the unit's reliability for critical functions.

7.10 AREAS OF CONCERN

Discussions with representatives of various airlines, the Avionics Maintenance Conference, and a few avionics manufacturers have identified a number of areas of concern related to the introduction of digital systems.

- TSO Compliance - The complexity of software in future digital systems could require extensive recertification procedures following software modification.
- Loss of Integrity - The use of integrity monitoring and fault flags should be sufficient to prevent the pilot from using equipment that is out of tolerance.
- Fault Propagation - A fault in one chip, circuit, unit, or subsystem can be manifested by a fault indication in another chip, circuit, unit, or subsystem. This phenomenon frustrates diagnosis and repair of system failure.
- Testability - Equipment design should incorporate sufficient self-testing capability to reduce the occurrence of unnecessary removals.
- Component Heating - Heat has always been a cause of system failure and continues to deserve attention even in digital designs.
- Electrical Power Spikes - Transients in power circuits occur frequently and can cause severe damage to avionics systems.
- Electromagnetic Interference (EMI) - Digital designs are not inherently less susceptible to EMI than analog systems. Although some new designs incorporate techniques to minimize EMI, EMI remains a problem.

CHAPTER EIGHT

CONCLUSIONS

The information obtained through consultation with numerous representatives of the aviation community indicates a positive attitude toward the capabilities offered by digital technology:

- MTBR in excess of 2,000 hours
- Extensive built-in-test and self-monitoring capabilities
- Increased functional capability
- Flexibility in integration

The systems evaluated did not exhibit problems that could adversely affect operational safety to any significant degree. Avionics manufacturers and aircraft operators agree in general that the economic consequences of avionics unreliability generate market forces that typically exceed the safety requirements of regulations. When design deficiencies are identified, timely corrective action is usually taken without regulatory prompting, because such action is in the best interests of both the avionics user and the manufacturer.

The reliability data obtained for this study were of the same nature as the data reported by AMC in the publication *PLANE TALK*. Differences in reporting methods (with respect to both systems reported on and reliability computation methods used) prevented a more comprehensive analysis beyond that performed.

If the data base on unit reliability were standardized, trend analysis could be applied to identify progressively worsening conditions. Expanding the data base to include information on the cause of failure would serve to stimulate design improvements.

Interviews with avionics users and manufacturers did identify some areas of concern regarding the implementation, use, and maintenance of digital systems:

- Effects of power transients
- Effects of electrical static discharge

- Requirements for software configuration control
- Requirements for dissimilar redundancy
- Effects of fault propagation
  - Detection
  - Isolation
  - Remedy

No attempt has been made in this report to develop or evaluate possible means of alleviating these concerns.

During the collection and analysis of the data presented in this report, a number of observations were made regarding the availability and interpretation of the data:

- Lack of standard definitions of "failure condition" and "digital"
- Variations in computation methods and reporting formats for system reliability
- Lack of general-aviation reliability data
- Uncertainty about why the removals-to-failures ratio remains as high for digital systems as for analog systems
- Difficult traceability of reliability records

Although these considerations posed problems during the study, close coordination between the participants made it possible to overcome the problems to a degree that was adequate for the study.

It should be noted that this study focused on only one aspect of digital technology: unit reliability. The continuing evolution of digital technology is affecting a number of areas:

- Redundancy techniques
- Functional capabilities
- Systems integration
- Maintenance practices
- Monitoring and voting techniques

As the evolutionary process continues to improve the implementation, use, and maintainability of digital systems, operational safety may be correspondingly increased.

APPENDIX

GLOSSARY

AC	Advisory Circular
ADF	Automatic Direction Finder
AMC	Avionics Maintenance Conference
ARINC	Aeronautical Radio, Incorporated
ATC	Air Traffic Control
BIT	Built-In Test
CDU	Control/Display Unit
COM	Communication
DME	Distance Measuring Equipment
ECS	Electronic Control System
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
FAR	Federal Air Regulations
GPWS	Ground Proximity Warning System
HF	High Frequency
ILS	Instrument Landing System
INS	Inertial Navigation System
LED	Light-Emitting Diode
LOC	Localizer
LRU	Line Replaceable Unit
MTBF	Mean Time Between Failures
MTBR	Mean Time Between Removals
MTBUR	Mean Time Between Unscheduled Removals
NAV	Navigation
RMI	Radio Magnetic Indicator
RTCA	Radio Technical Commission for Aeronautics
STC	Supplementary Type Certification
TSO	Technical Standard Order
VHF	Very High Frequency
VOR	VHF Omnidirectional Range

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